Zürcher Hochschule
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School of
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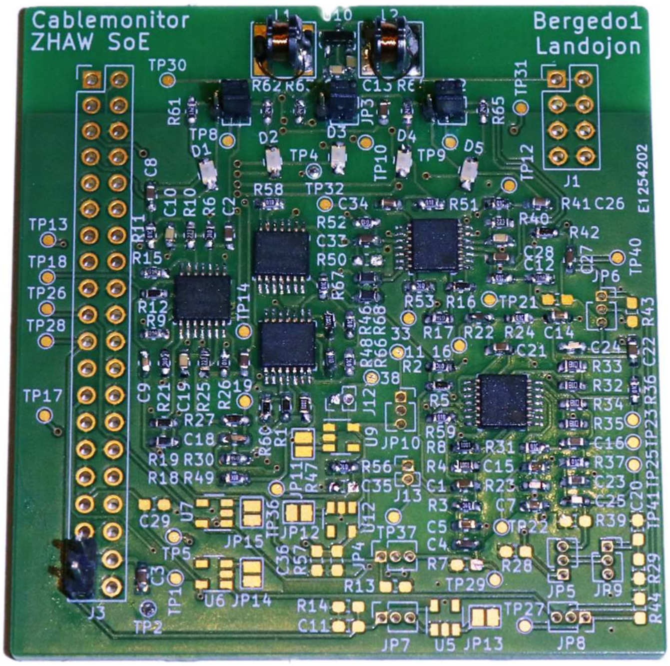
Autumn 2020

Hardware Report



Cable Monitor

ET.PM3-EN.P HS20 ET19aHS

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Date: 27.11.2020

Abstract

As part of the project module EPM3, a cable monitor had to be developed, which can detect a mains cable, measure the distance to the cable and the current which is flowing through it. Additionally, gathering experiences with project management and time keeping during an ongoing project are part of this course. The project contains a printed circuit board (PCB) to sense the fields emitted by the cable. The electrostatic field is measured by pads and the electromagnetic field with coils or a hall sensor. The signals gathered by the pads, coils and hall-sensor are very weak and noisy. In order to measure the signals with an ADC, they first must be amplified and filtered. Several solutions have been implemented to increase the robustness of the circuit and to be able to choose the best working circuit. The signals can be filtered by an active Butterworth low pass third order or a passive RC low pass. A cable can be detected and the output signals from the PCB measured with the oscilloscope allow conclusions about the distance of the cable. The current can be measured with a coil. Nevertheless, the signals from the first measurement on the oscilloscope, showed low amplitude and high noise. However, as several solutions had been implemented it was possible to skip a part of the circuit, as it was not working as intended. Although the implemented solution is functional, the authors would have designed the circuit differently at the time of submission. Circuits as the diode clamper or the peak rectifier with an opamp and diode were unknown and therefore not used.

Table of Content

1. Introduction

The topic of this project is to design, build and test a PCB for the EPM3 project, which is a cable monitor. A wire connected to the mains electrical grid radiates an electrostatic field. The strength of the field decreases with distance. The task is to measure the electrostatic and electromagnetic field of a 230V/AC cable. These two measurements are intended to determine the direction of the cable and the current flowing through it. The PCB to be designed is the sensor board with the measurement, filter, and amplification on it. The signals are then transferred to a STM32-Discovery board through a given baseboard. There the signals is digitized and analysed.

This document is the main documentation for the hardware created. The following pages aim to understand the reasoning and decisions made during the project.

2. Specifications

The specifications of the cable monitor can be separated in mandatory and optional criteria [1]. Table 1 lists them accordingly:

Table 1: Specifications of the cable monitor.

Mandatory	
No.	**Description**
1	Detect mains cable at a distance of up to 200mm
2	Display the distance to the cable in the range 5mm to 100mm with a precision of ±30%
3	Display if the cable is left or right of the device
4	Battery powered, preferably with auto shut down when no longer used
5.0	Accurate measurement (averaging: mean and standard deviation)
5.1	Single measurement
Optional	
6	Display current in the range of 1A to 10A with a precision of ±50%
6.1	For a single-phase wire (at mains potential) up to a distance of 10mm
6.2	For a cable with phase, neutral and protecting earth up to a distance of 5mm
7	Turning the cable monitor off
8	Calibration of distance (with look up table in non-volatile memory)
9	Alarm (Overcurrent, Distance)

3. Evaluation

3.1. Virtual ground (VGND)

Because the whole system is powered with two AA batteries (Vcc = 3V), negative supply voltages are not available. All operational amplifier (opamp) circuits use a single supply with a virtual ground (VGND) with potential at half of the battery voltage, which allows to use the negative parts of the signals. A fixed voltage reference is not useful, as the supply voltage can drift with weaker batteries. A resistive voltage divider is used to hold VGND at VCC/2.

A symmetrical supply voltage is not used, because the students wanted to gather experience with opamp circuits with VGND.

3.2. Electrostatic field sensing

In order to detect and measure the distance to a mains cable, the emitted electrostatic field (e-field) from the cable must be measured. The strength of the electrostatic field depends on the distance and therefore the distance can be calculated.

To pick up the electrostatic field, a copper plane (pad) on the PCB acts as an antenna. The alternating voltage causes an alternating current in the pad-to-wire capacitor. This current generates a voltage which can be measured. Since this voltage is very small and noisy, an amplifier and filter must be added. After amplifying and filtering, the signal can be measured by the ADC. This process is shown in Figure 1:

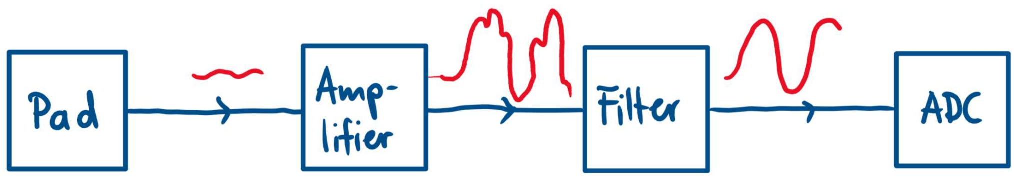


Figure 1: Block diagram for the electrostatic field sensing.

For detecting the relative location of the mains cable to the cable monitor, at least two pads are needed. The pad which generates a higher voltage is located closer to the cable. However, with two pads only two directions (left/right of device) can be differentiated. In order to get a higher resolution, three pads are implemented on the PCB. The pads should be aligned on the front side of the PCB and placed closely together. The direction of the mains cable will be indicated by LEDs, which are aligned on a circle.

3.2.1. **Filter**

Since the highest frequencies are 50Hz, a lowpass is sufficient to filter our signal. Noise levels at these low frequencies are very low, therefore it is not necessary to design a band pass. In other words, the higher component costs and complexity outweigh the benefits.

An active low pass third order will be designed. However, this filter is at a higher risk of failure and therefore a simple and robust passive RC low pass is implemented as well. Furthermore, a jumper will be used to switch between the two implementations.

3.2.2. **Amplifier**

For amplifying, a non-inverting amplifier is used. Not only does it amplify the signal but it also acts as an impedance converter.

3.3. Electromagnetic field sensing

To be able to measure the current trough a wire, the emitted electromagnetic field must be measured. As proposed from the lecturer and in the template, a coil is used to sense the electromagnetic field. To measure currents even when the field lines are exactly perpendicular to the coil, two coils are used. Similar to the sensing of the electrostatic field, the signal is very small and an amplifier is needed.

Another option to measure the electromagnetic field are hall-sensors. Since there is enough space on the PCB, two coils and an additional hall-sensor are implemented. This configuration allows to choose the better working solution.

4. Development

4.1. Virtual ground (VGND)

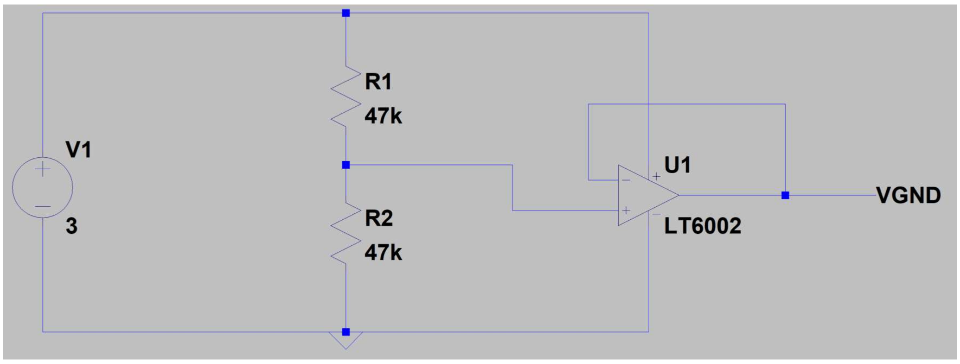


Figure 2: Generation of VGND.

As shown in Figure 2, the VGND is created with a voltage divider from the supply voltage. For a longer battery life two 47kΩ resistors are used. In order to stabilize the VGND, an impedance converter is used.

4.2. Electrostatic field sensing

4.2.1. Butterworth low pass third order

After researching online about higher order filters, an example of a Butterworth low pass third order has been adapted [2].

The amplification of the filter is not changed. The cut off frequency is set to 70Hz to prevent the 50Hz target signal from attenuation:

$$f_c = \frac{1}{2\pi * R * C} \; ; \; R \; defined \; as \; 10k\Omega$$

$$C = \frac{1}{2\pi * R * f_c} = \frac{1}{2\pi * 10k\Omega * 70Hz} = 227.36nF$$

A 220nF capacitor is selected:

$$f_c = \frac{1}{2\pi * R * C} = \frac{1}{2\pi * 10k\Omega * 220nF} = 72.34Hz$$

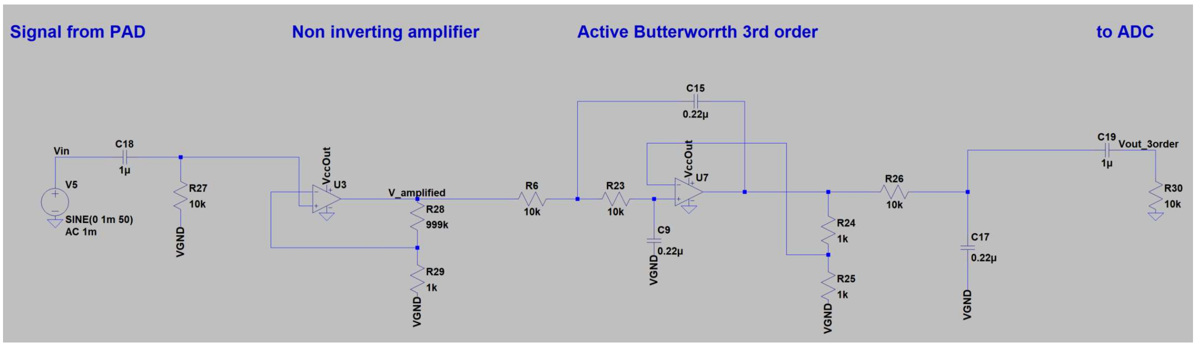


Figure 3: Amplifier with following Butterworth third order.

The signal from the pad is decoupled, amplified and filtered to be measured by the ADC, which is shown in Figure 3.

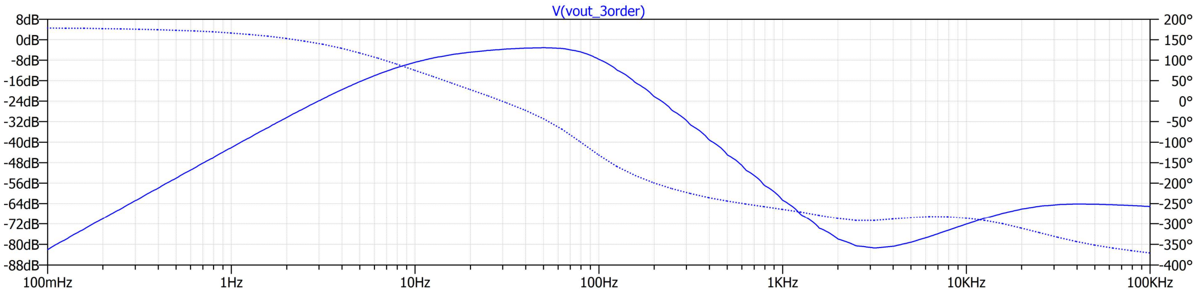


Figure 4: Bode plot of the Butterworth third order.

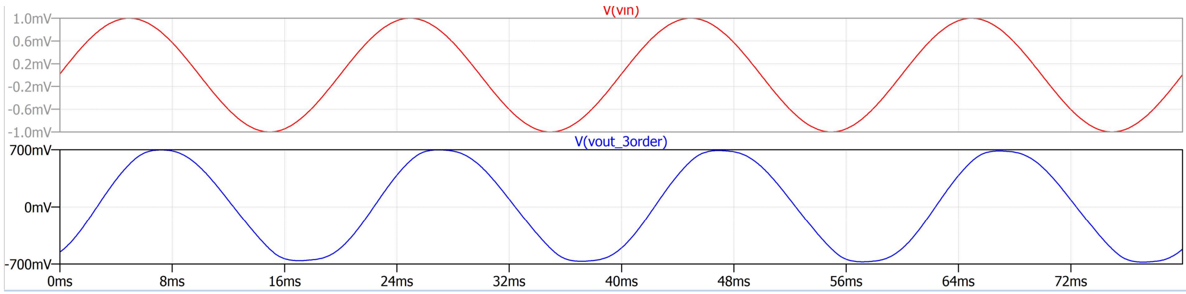


Figure 5: Amplified and filtered output signal.

As illustrated in Figure 4, the decoupling to VGND, which is a high pass filter itself, generates a bandpass behaviour for the whole filter. This is suitable for the application of the cable monitor, since only frequencies around 50Hz are of interest. As the application is not time-critical, the phase shift of the Butterworth can be ignored.

As shown in Figure 5, Vin (red) with 2mVpp is amplified to Vout (blue) with roughly 1.5Vpp. The pads should be designed as big as possible in order to get the highest possible amplitude.

4.2.2. **RC lowpass first order**

Due to the lower order, the cut-off frequency is set closer to the 50Hz target signal as with the third order. A cut off frequency of 60Hz is chosen:

$$f_c = \frac{1}{2\pi * R * C} \; ; \; R = 22k\Omega$$

$$C = \frac{1}{2\pi * R * f_c} = \frac{1}{2\pi * 22k\Omega * 60Hz} = 120.57nF$$

A 120nF capacitor is selected:

$$f_c = \frac{1}{2\pi * R * C} = \frac{1}{2\pi * 22k\Omega * 120nF} = 60.28Hz$$

The filter is placed after decoupling to VGND. After filtering, a non-inverting amplifier amplifies the signal, which is shown in Figure 6.

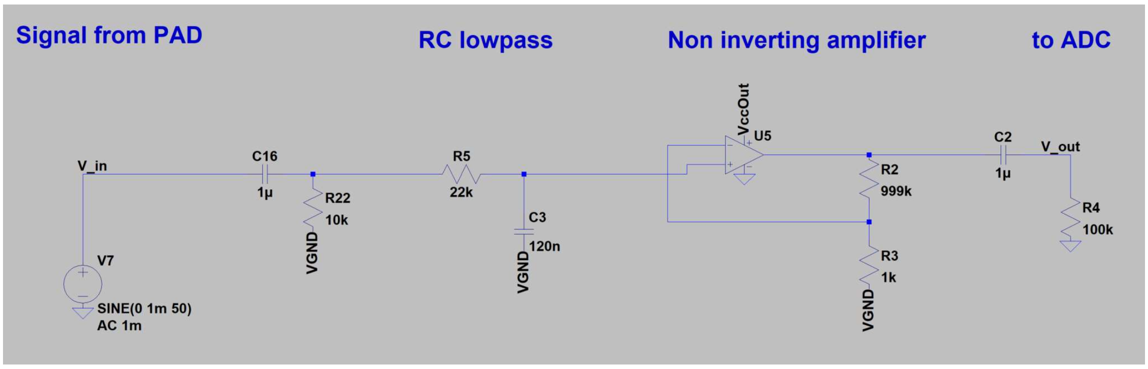


Figure 6: RC lowpass filter with amplifier.

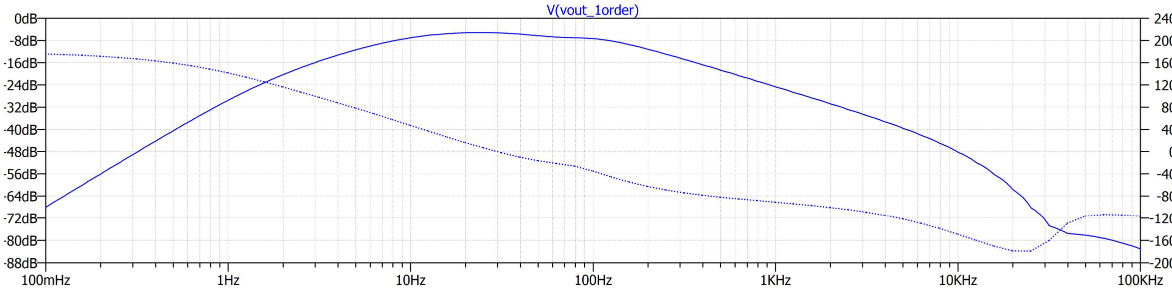


Figure 7: Bode plot of the RC lowpass filter.

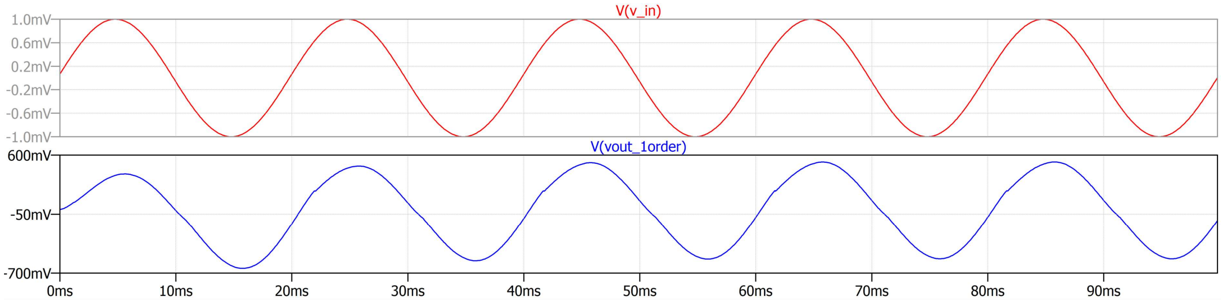


Figure 8: Amplified and filtered output signal.

Similar to the Butterworth, the decoupling to VGND generates a bandpass behaviour, which is shown in Figure 7. It is suitable for our application and the phase is not of importance again.

As shown in Figure 8, the input signal Vin (red) with 2mVpp is amplified to Vout (blue) with roughly 1.1Vpp.

4.2.3. Comparison

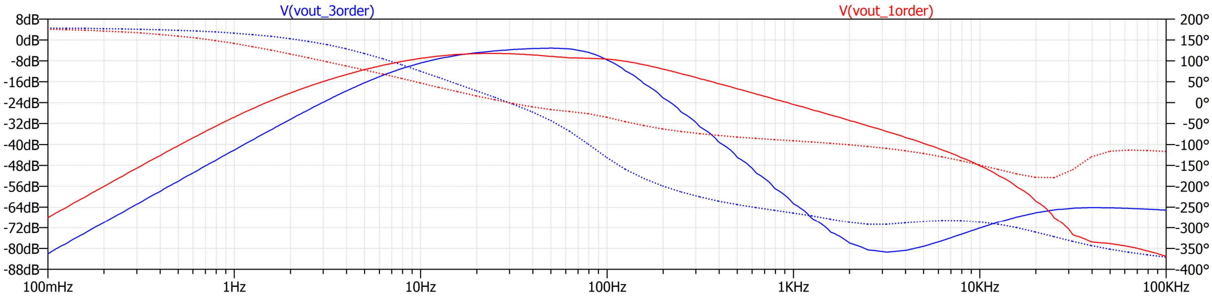


Figure 9: Comparison bode plot lowpass third order (blue) and low pass first order (red).

As shown in Figure 9, the attenuation of the third order filter is, as expected, considerably higher. Whether this will have a major influence on the distance measurement cannot be said at this stage.

4.3. Electromagnetic field sensing

4.3.1. Coil

As shown in Figure 10, an impedance converter is used after decoupling to prevent the induced voltage in the coil from collapsing immediately due to a connected load. After the impedance converter, the signal can be amplified by a normal inverting amplifier.

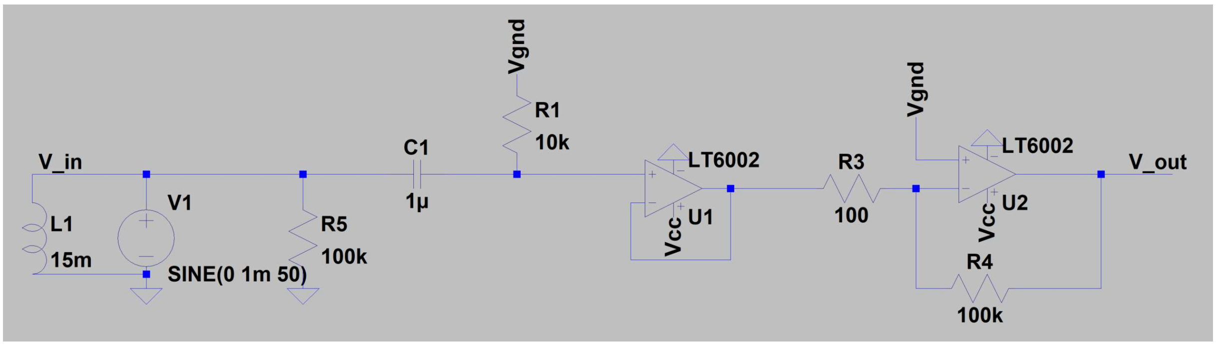


Figure 10: Impedance converter and amplifier for electromagnetic field sensing.

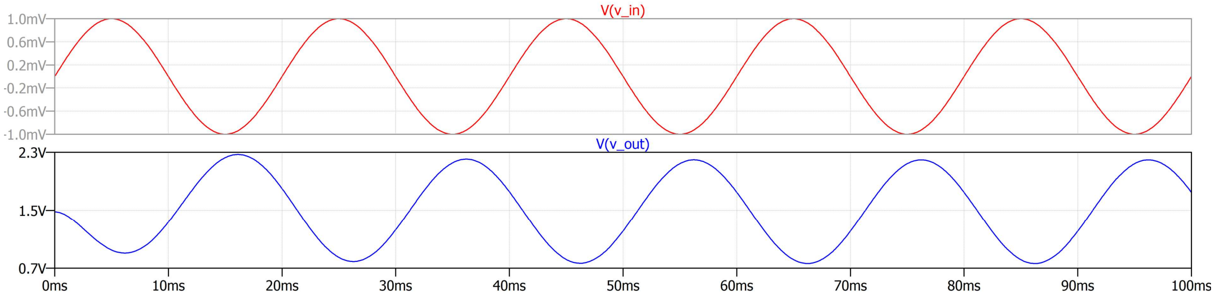


Figure 11: Input/output signals electromagnetic field sensing.

As shown in Figure 11, the input signal Vin (blue) with 2mVpp is amplified to Vout (red) with roughly 1.5Vpp.

4.3.2. **Hall-sensor**

The same hall-sensor as proposed from the lecturer (DRV5053) is selected. The output changes according to the measured electromagnetic field as shown in Figure 12. If no field is present (0 Tesla), the output is held at 1V. If a field is present, the output will change in a linear fashion from 1V according to the direction of the field:

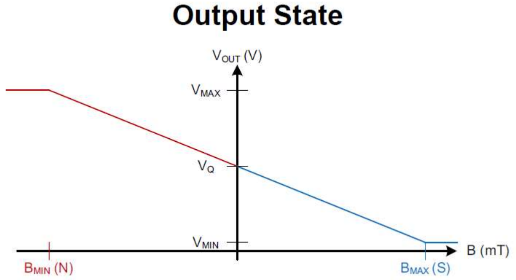


Figure 12: Output voltage of the hall-sensor in respect to the magnetic field.

With the given sensitivity and maximum current (see specifications in Table 1) the output change can be calculated for every distance to the wire. As shown in Figure 13, the change of the output decreases drastically with increasing distance.

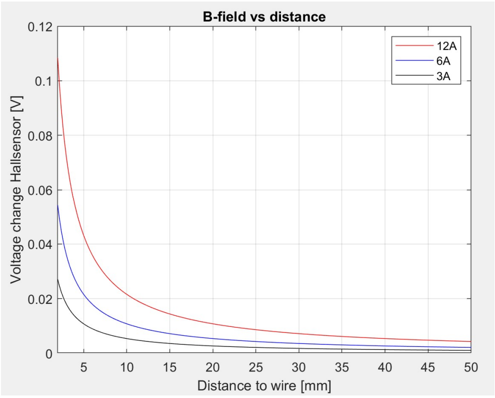


Figure 13: Change in output voltage of the hall-sensor for different currents.

The small difference to the zero state (1V) must be amplified. A normal amplifier will not work because the offset always puts the opamp in saturation. After building the difference to 1V, a normal amplifier can be added, which is shown in Figure 14. Since the hall-sensor has an internal filter, no external filtering is required.

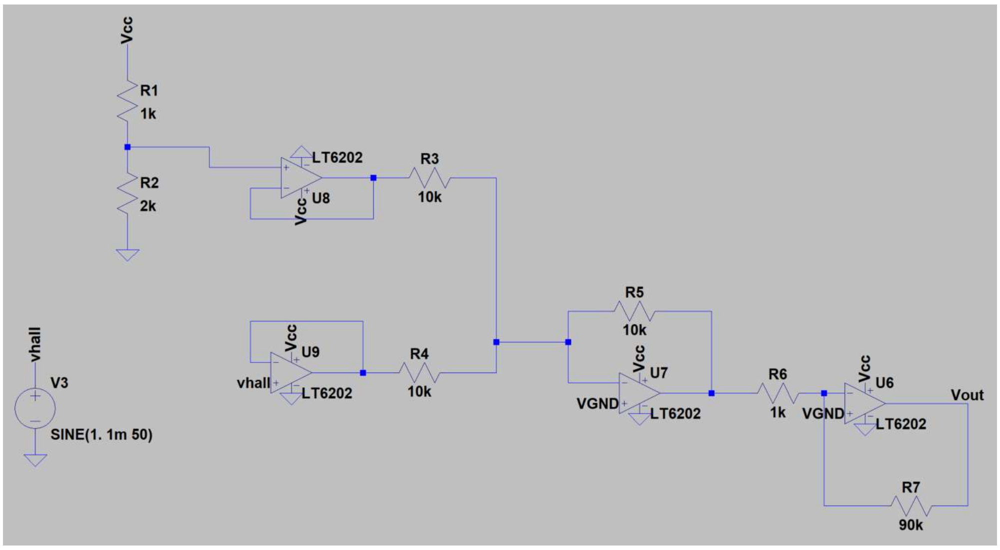


Figure 14: Hall-sensor circuit.

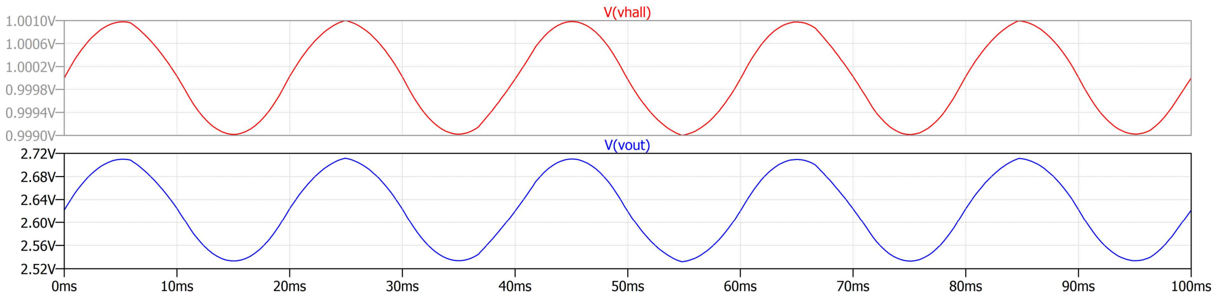


Figure 15: Input and output signal of the hall-sensor.

The output signals are shown in Figure 15. The difference from the hall-sensor (2mVpp) is amplified to roughly 0.2Vpp

4.4. Opamp

The proposed opamp from the lecturer (MCP6002) has an offset voltage of 9mV. This would severely distort the measurement as the signals can be smaller than 9mV, especially if multiple opamps are used in series. To minimize this error, an opamp with lower offset voltage is used.

The OPA4376 has a typical offset voltage of 5µV, which is 1800 times smaller than the offset voltage of the MCP6002. Furthermore, the gain bandwidth product (GBP) of 5.5MHz still allows a gain of 100dB at 50Hz, which is sufficient. The OPA4376 is available as a quad version in a TSSOP-14 package, which makes the layout easier as only one supply is needed for 4 opamps.

The OPA4376 is sufficiently accurate for our ADC because the offset voltage is smaller than it's resolution:

$$V_{res} = \frac{Vdd_A - Vss_A}{2^{res}} = \frac{3V - 0V}{2^{12}} = 0.73mV$$

4.5. Peak value rectifier

To minimise the complexity of the software, an ideal diode is used to build a peak value rectifier. Every signal from the electrostatic and electromagnetic measurement is rectified. The diode D1 in Figure 16 is only for simulating purposes and is replaced with an IC which behaves like an ideal diode (see chapter 5.1.6).

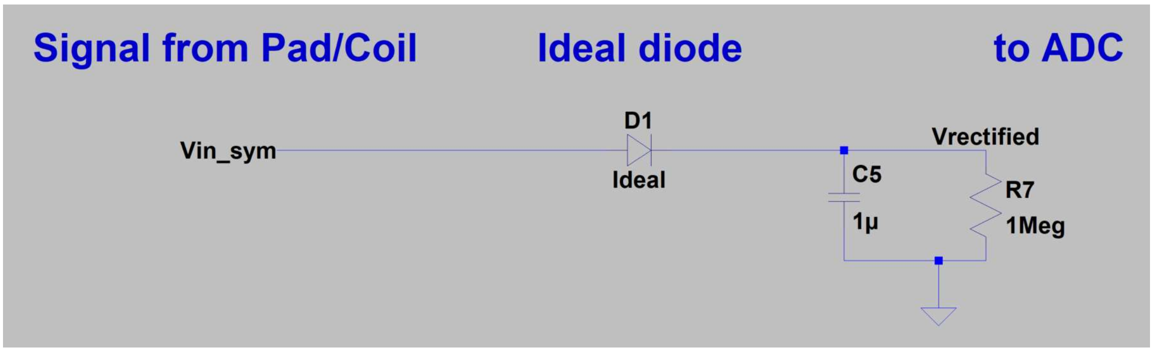


Figure 16: Peak value rectifier with an ideal diode.

The rectified signal, as shown in Figure 17, can be measured much faster by the ADC, because it is not necessary to observe a whole period to find the peak value. On the other hand, the system gets more unresponsive to fast signal changes, which is not a problem in this application.

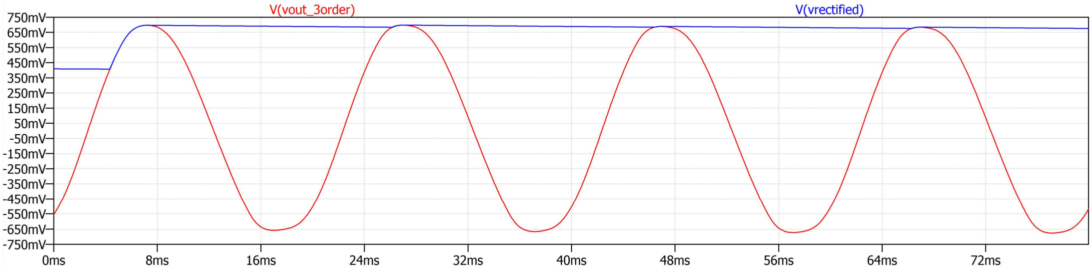


Figure 17: Peak rectified signal.

4.6. LEDs

To safe space on the PCB, a LED in a 0805 package is chosen. The LH R974 is a red LED with a forward voltage of 1.8V, which is below 3V and therefore suitable for our application. The maximal forward current is specified with 30mA. Any GPIO pin from the SMT32 can sink a current up to 25mA, which is shown in Figure 18:

Table 15. Current characteristics

Symbol	Ratings	Max.	Unit
ΣI_{VDD}	Total current into sum of all V_{DD_x} power lines (source)(1)	270	mA
ΣI_{VSS}	Total current out of sum of all V_{SS_x} ground lines (sink)(1)	− 270	
I_{VDD}	Maximum current into each V_{DD_x} power line (source)(1)	100	
I_{VSS}	Maximum current out of each V_{SS_x} ground line (sink)(1)	− 100	
I_{IO}	Output current sunk by any I/O and control pin	25	
	Output current sourced by any I/Os and control pin	− 25	
ΣI_{IO}	Total output current sunk by sum of all I/O and control pins (2)	120	
	Total output current sourced by sum of all I/Os and control pins(2)	− 120	
$I_{INJ(PIN)}$ (3)	Injected current on FT pins (4)	− 5/+0	
	Injected current on NRST and BOOT0 pins (4)		
	Injected current on TTa pins(5)	±5	
$\Sigma I_{INJ(PIN)}$(5)	Total injected current (sum of all I/O and control pins)(6)	±25	

Figure 18: Section of the datasheet STM32.

In order to drive the LEDs directly with the microcontroller and guarantee a longer battery life, a forward current of 5mA is chosen:

$$V_{F\,typ} = 1.8V; \quad I_F = 5mA$$

$$R_{ser} = \frac{V_{CC} - V_F}{I_F} = \frac{3V - 1.8V}{5mA} = 240\Omega$$

$$P_R = \frac{(V_{CC} - V_F)^2}{R_{ser}} = \frac{(3V - 1.8V)^2}{240\Omega} = 6mW$$

A 240Ω 0603 1/10W resistor is selected.

5. Implementation

5.1. Schematic

The schematic is the combination of the simulated circuits. It contains the board-to-board connectors, indicating LEDs to visualise the direction of the cable, the power supplies of the ICs, the generation of the VGND, and the circuits to decouple, filter, and amplify the sensor signals. In the following chapter, the circuits described in the previous chapter are applied to the schematic.

5.1.1. Board-to-board connectors

In Figure 19, the given pinout of the connectors from the baseboard to the sensor board is shown. J1 is connected to GND only. J3 is connected to the baseboard, where it is wired to the microcontroller board. PC1, PC3, PF8, PF6 and PA5 can be activated as ADCs internally on the microcontroller board. Because of more signals in need of analog-digital-conversion than ADCs are available, the signal of the coil 1 or the hall-sensor can be connected to the ADC in PC1 using J10. The second coil and the pads are directly connected to the ADCs.

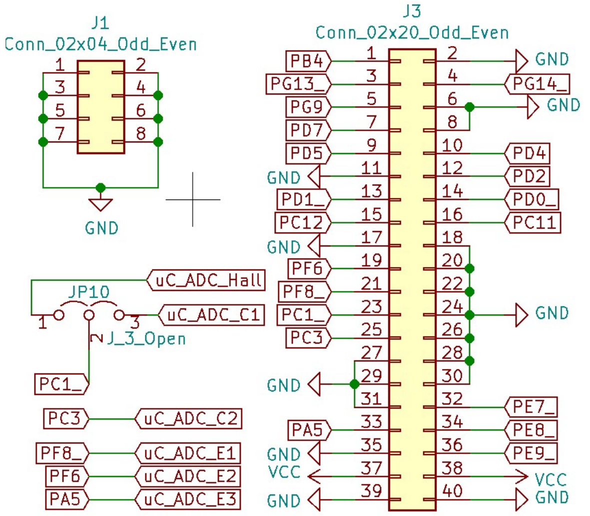


Figure 19: Board-to-board connectors and jumper to swap between coil and hall-sensor.

5.1.2. Power supply

In Figure 20, the power distribution to each opamp is shown. The capacitors C6, C30, C32, C37, and C38 are buffer capacitors, one for each opamp. The buffer capacitors help to prevent the opamps from oscillating and stabilize their power supply.

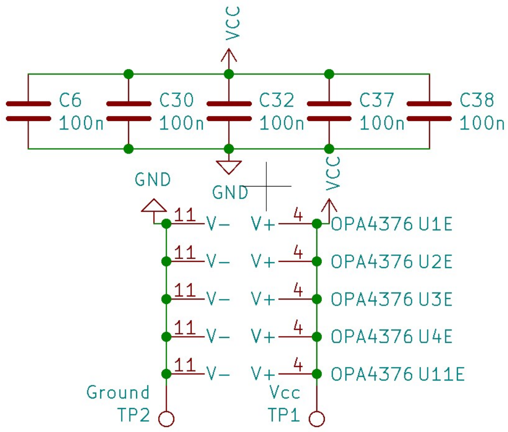


Figure 20: Power distribution to the integrated circuits with buffer capacitors.

5.1.3. Virtual Ground (VGND)

As described in chapter 4.1, the VGND is generated using a resistive voltage divider with an impedance converter. C3 supports the voltage divider, to get a continuous and distortion free VGND.

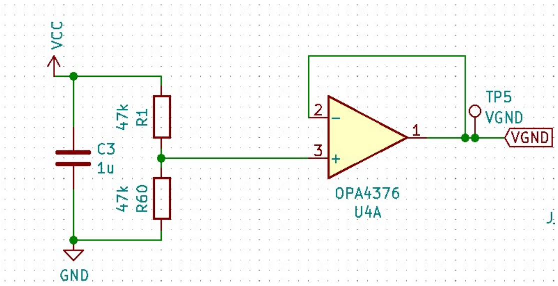


Figure 21: Generating the VGND with a resistive voltage divider.

5.1.4. Direction indicating LEDs

The LEDs in Figure 22 are connected over resistors to VCC and to the microcontroller board. This allows the microcontroller to sink the LEDs to ground in order to turn them on.

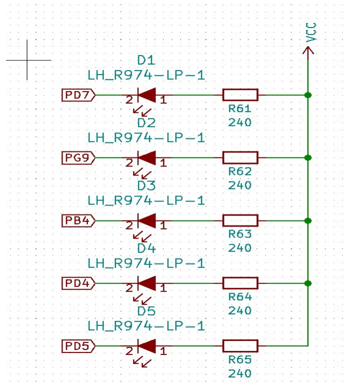


Figure 22: LEDs for indicating the direction of the cable.

5.1.5. Coil

The circuit shown in Figure 23 corresponds to the simulation. L1 catches an electromagnetic field. The signal is decoupled by C33. U2C is an impedance converter and the signal is amplified by U11B. The amplified signal is directed to the peak value rectifier.

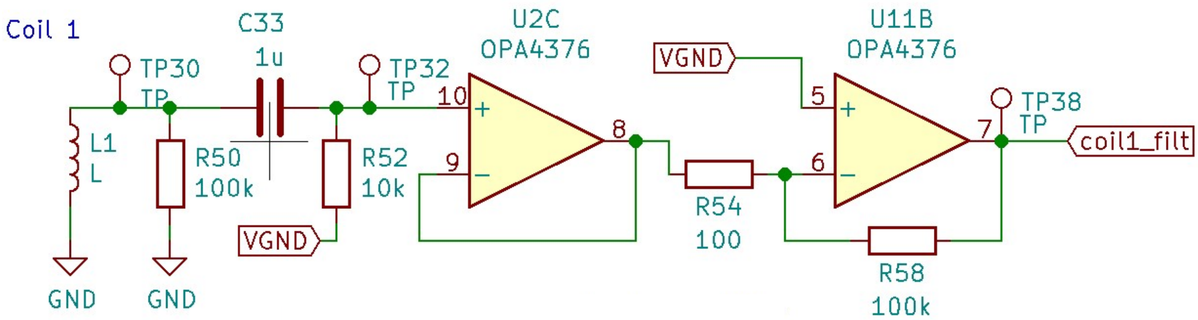


Figure 23: Circuit for the coils with decoupling and amplification.

5.1.6. Peak value rectifier

Figure 24 shows the schematic application of the peak value rectifier. U9 is an ideal diode, MAX40200AUK, that is used to cut off the negative halfwave. After the diode, a capacitor follows to generate a continuous voltage that equals to the peak voltage of the signal. The purpose of R56 is to allow the capacitor to discharge and to keep the continuous voltage agile to changes in the peak voltage. J12 is used to bypass the diode in case the diode does not work as expected. J11 is a solder bridge that deactivates the diode if it is bridged to prevent interference with the signal behind it.

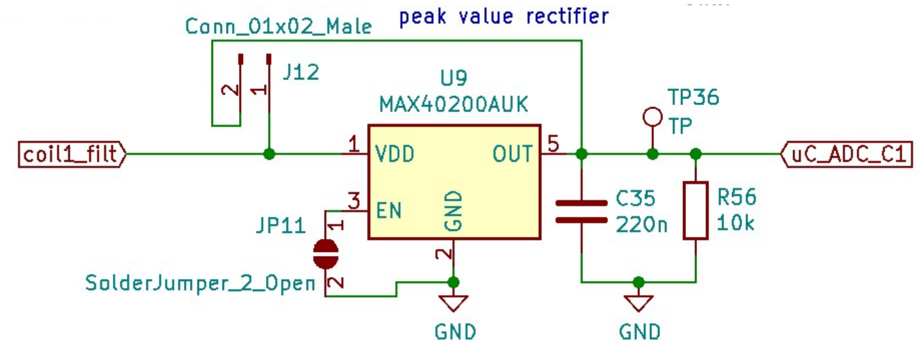


Figure 24: Peak value rectifier with ideal diode MAX40200AUK.

5.1.7. Electric field pad

The circuit in Figure 25 corresponds to the simulation. The jumper JP1 is used to swap the signal between the Butterworth filter and the passive filter. Same applies to jumper JP4. JP7 can bypass the diode and JP13 can disable the diode in case of unexpected behaviour of the ideal diode. C11 and R14, as well as U5, are part of the peak value rectifier described in the previous paragraph. Different to the development, the amplification stage was set before the Butterworth filter in order to amplify the signal closer to the sensor to avoid distortion during the filtering process.

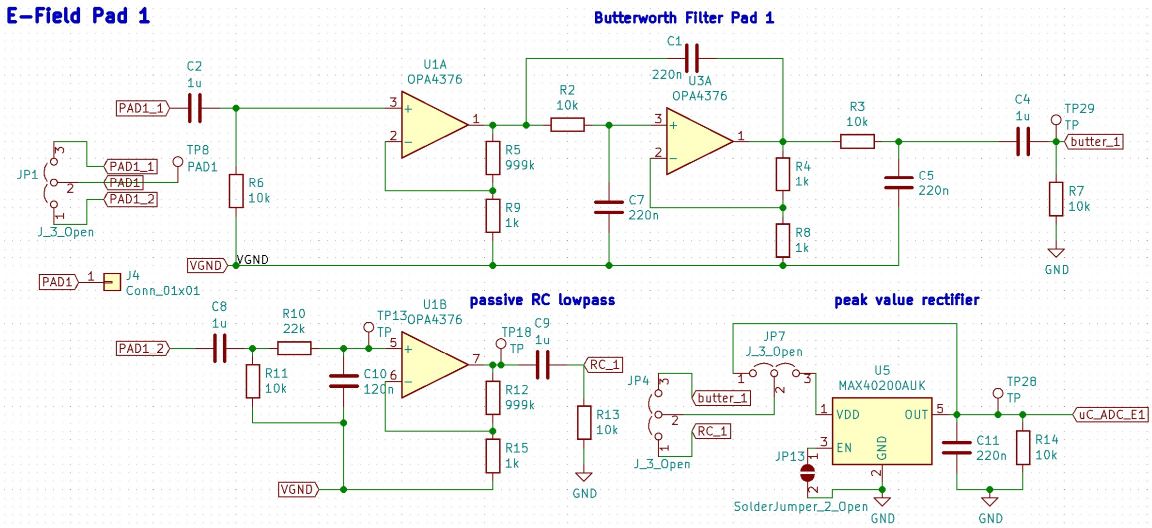


Figure 25: Circuit for the pads with Butterworth and passive filters, and amplification.

5.1.8. Hall-sensor

In Figure 26, the hall-sensor and all the corresponding circuits are shown. U4B, R47 and R49 generate 1V, U11A decouples the hall-sensor. The difference is then built using U4C. U4D amplifies the signal for the ADC. The circuit is further described in chapter 4.3.2.

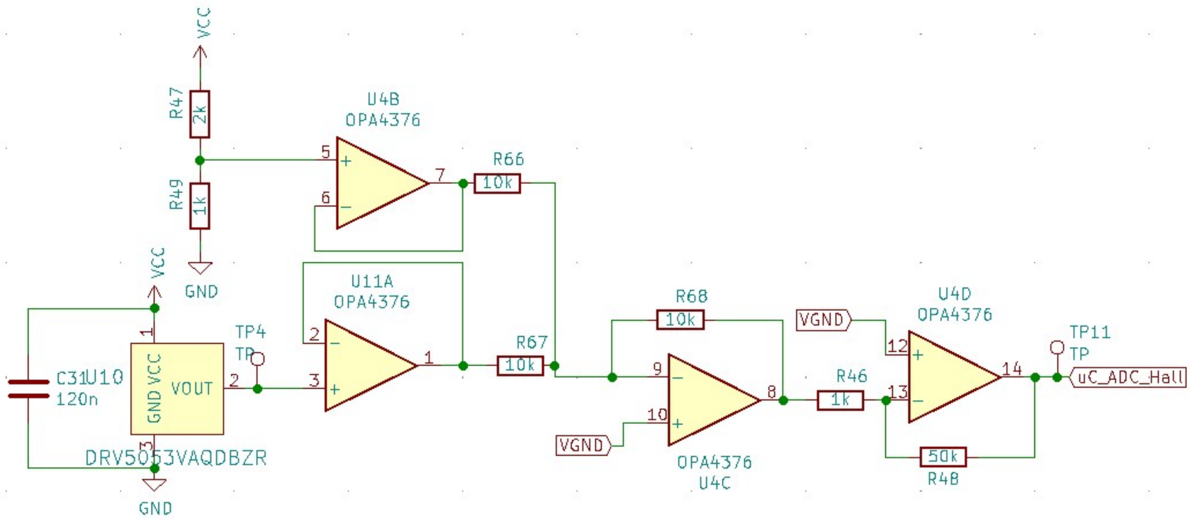


Figure 26: Hall sensor circuit with adding amplifier and amplification stage.

5.2. Layout

On the top layer there is a ground plane. The bottom plane is filled with a plane connected to VGND. The board-to-board connectors were placed first, as their position is fixed. Then the LEDs were placed on a circle centred in the middle of the lower edge of the PCB (Figure 27, green area). The sensors had to be placed in front of the board to be as close to the signal source as possible. There are no planes on the top or bottom side around the sensors as they could cause distortion (Figure 27, blue area). The amplification stage was placed close to the sensors, to be more flexible with the filtering stages and less susceptible to distortion during the filtering process. For less signal distortion, all the wire edges are kept in 45° angles. Greater angles were not used. In addition, unconnected planes and unnecessary plane tips were removed.

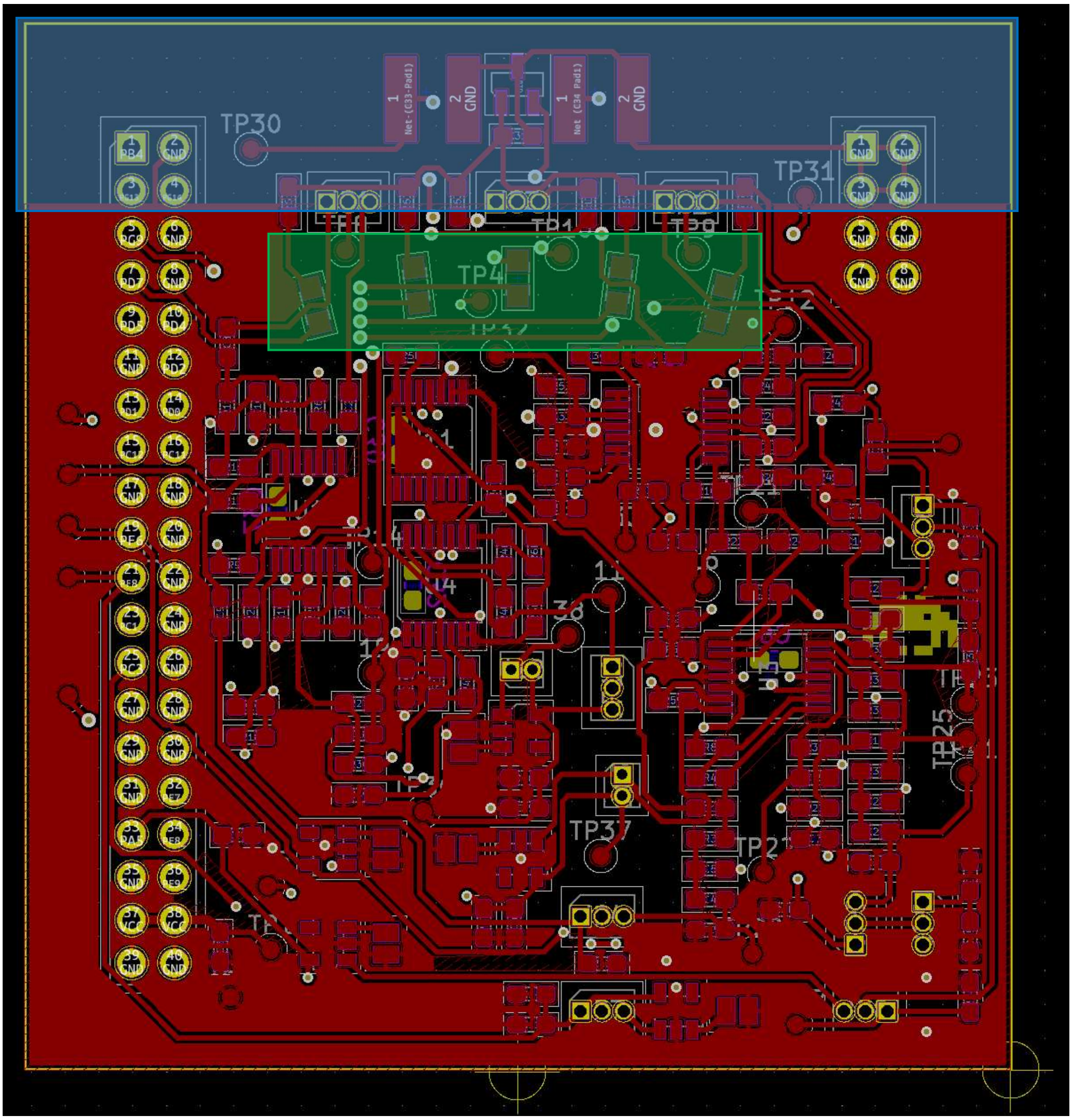


Figure 27: Layout top layer of PCB, LEDs in green area, Sensors in blue area.

6. Test

Unless otherwise specified, all measurements are in respect to GND. Only one pad, one coil and the hall-sensor were measured. The additional pads and coils are copies of the first one. A summary of the most important measurements can be found in Table 2. The complete measurements are located in the appendix.

Table 2: Summary of testing

Test item, Description	Test conditions	Expected, Tolerance	Measured result	Comparison, verdict	Remarks, Discussion
VGND	3V Supply	1.5V±5%	1.54V	Test passed	
Pad Butterworth filter	Cable 5mm from pad	Output signal: >1.3Vpp	1.6Vpp	Test passed	
Pad passive filter	Cable 5mm from pad	Output signal: >1Vpp	0.82Vpp	Test partly passed	Adjust gain
Pad peak value rectifier	Input signal: filtered pad signal, diode enabled	Upper half wave cut off, Signal from 0-Vpp Volt	No rectified signal	Test failed	Skip circuit and adjust decoupling
Coil amplification	Cable with 5A 30mm from pad	Output signal: >1Vpp	0.5Vpp, noisy	Test partly failed	Add filter
Coil peak value rectifier	Input signal: Amplified coil signal	Upper half wave cut off, Signal from 0-Vp Volt	No rectified signal	Test failed	Skip circuit and adjust decoupling
Hall-sensor signal amplified	Cable with 5A 5mm from pad	~0.2Vpp	1Vpp, noisy	Test passed	Add capacitor and rotate PCB

6.1. Modifications

As the peak value rectifier does not work as expected, it is skipped by the foreseen jumper. In order not to bring negative signals to the ADC, the decoupling before the peak value rectifier is not populated. The capacitor and the resistor after the ideal diode are not populated either because it would affect the output signal.

The resistive voltage divider for the hall-sensor is not implemented correctly in the schematic: the values of R47 and R49 must be switched. R47 is 1kΩ, R49 is 2kΩ.

The signal output of the hall-sensor is very noisy. Therefore, a capacitor (2µF) is added before the impedance converter in order to bring the noise down.

As the signal of the coil is very noisy, a low pass RC with fc=72.3Hz is added.

6.2. Outcome and post processing

The measurements in Table 2 indicate that there is more signal amplitude possible. Therefore, tuning the amplifiers can help to maximise the signal output. The tuning could not be completed until the deadline of the hardware report because of the lack of a wide range of resistor values in the required size.

7. Project management

The Gantt Chart in Figure 28 visualises the timeline of the project. In response to the circumstances, the schedule had to be adjusted in week six. The main changes concern devoting more time to the hardware part and reducing the time for the software, as a sample software already exists, as well as delaying milestones and deadlines.

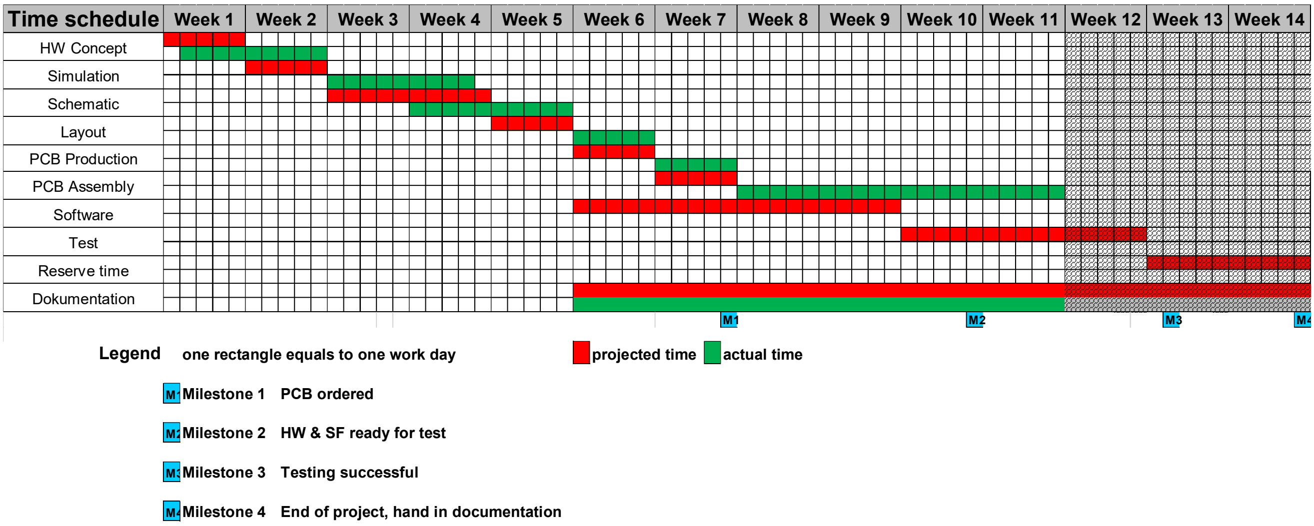


Figure 28: Gantt Chart with milestones and comparison of actual and projected workload.

7.1. Work packages

The following work packages were planned:

- Design and simulation, Berger
- Schematic and layout, Landolt
- Hardware assembling and testing, Berger & Landolt
- Hardware Report, Berger & Landolt
- Software, Berger & Landolt

7.2. Comparison of planned and real workload

The real workload exceeded the initially planned amount by far. Therefore, the schedule was redone in week six. However, it was still tight, as the overall time did not change.

One reason was that the simulations were more complex than expected. Unexpected effects, such as oscillating opamps and the decoupling of the AC signals required more time than planned.

As time was limited, no simulations were made with the actual circuit on the schematic to verify the functionality. This led to errors on the schematic, for example, one missing resistor in the Butterworth filter. Evaluating the importance of the resistor and measuring the effects took time that was not scheduled.

Moreover, testing took much longer than expected, as measurements had to be done multiple times. Resistor values had to be adjusted, in order to get a sufficient signal output, for example to compensate filter attenuation. This required to measure all the signals after the change again. The expected input values at the sensors were sometimes immeasurable by the oscilloscope and too small to be generated by the function generator. Therefore, additional circuits had to be built on a breadboard. In addition, delays were caused by errors such as wrongly set jumpers and disturbance from a nearby soldering iron.

For the above reasons, the schedule has been extended by three weeks so far due to hardware testing.

8. Conclusion

8.1. Achieved results

The overall outcome of the hardware is satisfying as all the signals can be processed and all circuits work. On the other hand, some mistakes were made but all could be solved effectively and without excessive modifications. It was a good decision to implement more than one solution and have jumpers to skip parts of the circuits. Even though we could not measure any outcome from the pads or the coils, after the amplification a signal becomes visible and measurable. The simulation is consistent with the measured values. The simulation helps a lot to find possible errors and to test how modifications affect the circuit and output signal without having to make changes to the actual PCB.

8.2. Reflection

This project started at the same time as electronics 1, where opamp circuits are taught. Some of the better suited circuits were only taught halfway in the semester. The diode clamper and the ideal diode circuits would have been very helpful but were only covered as the design of the project had already advanced too far. In hindsight, more stable and cleaner solutions could have been implemented.

As the decoupling of an AC signal with a capacitor and a resistor has the side effect of being a high pass filter, the decoupling affects the signal in shape and amplitude. Therefore, a symmetrical supply voltage should have been considered more. With a symmetrical supply voltage, negative signals would not have been a problem and could have been lifted in the last stage with a diode clamper circuit to be measurable for the microcontroller. A negative supply voltage would have also helped the imagination, as 1.5V as a new reference is more abstract

To save space quad opamps were used. Hence, some of the opamps were unused and some inputs were left floating. In future, these should be connected to GND to prevent them from surging supply current and affecting the circuit by unexpected behaviour.

With an earlier introduction of the hardware report, some mistakes in the circuit design could have been prevented, as writing gives the chance to rethink what was done and thought during the development process.

If a new component is used which is not known, the data sheet should be studied carefully to avoid errors. In our case, the error with the ideal diode could have been easily prevented.

After all we are satisfied with the hardware of our cable monitor. Besides the measurable results also the personal progress achieved in this project deserves mentioning. Mistakes were made because of a lack of knowledge but also because of inexperience. This was the first complete project to be done within a tight schedule without very clear expectations and instructions. Searching the way to the solution alone and keeping motivation even when the project seems not to be working and having no ideas anymore why problems occur, were crucial lessons learned.

9. References

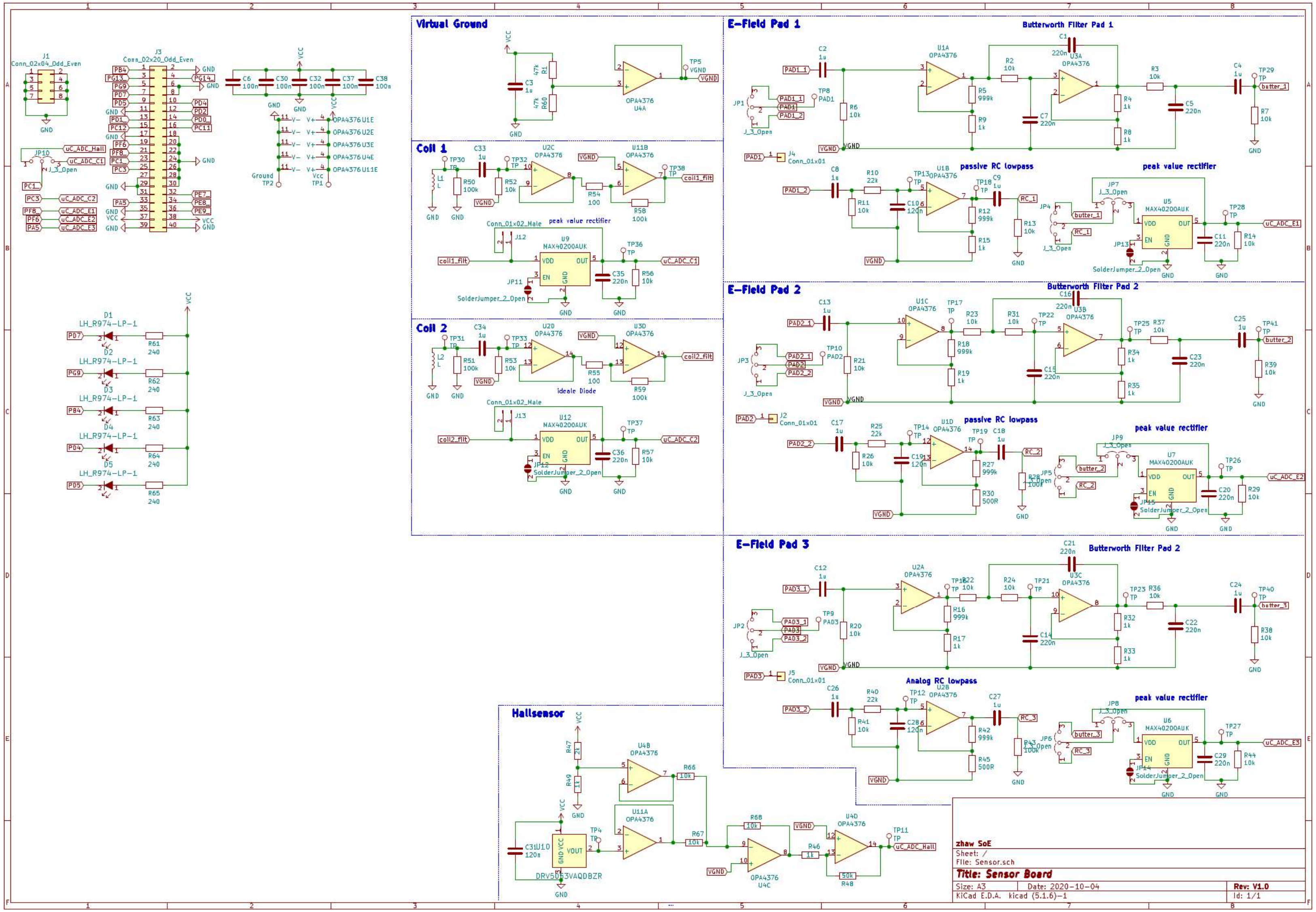
[1] H. Hochreutener. (2020, March 4). *Electronics Project 1: Cable-Monitor* [Course material] Not public.

[2] n.p. (2020). *Butterworth Filter Design* [Online]. Available: https://www.electronics-tutorials.ws/de/filtern/butterworth-filter-design.html [26.11.2020]

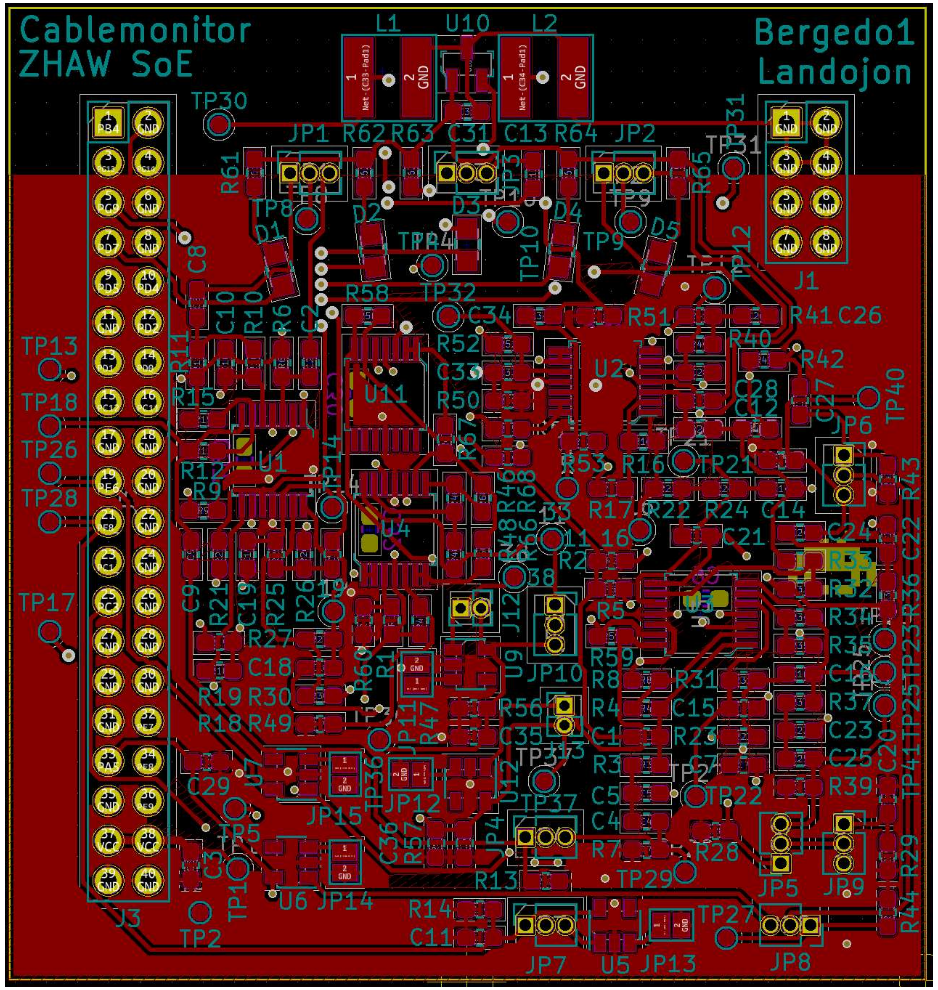
10. List of figures

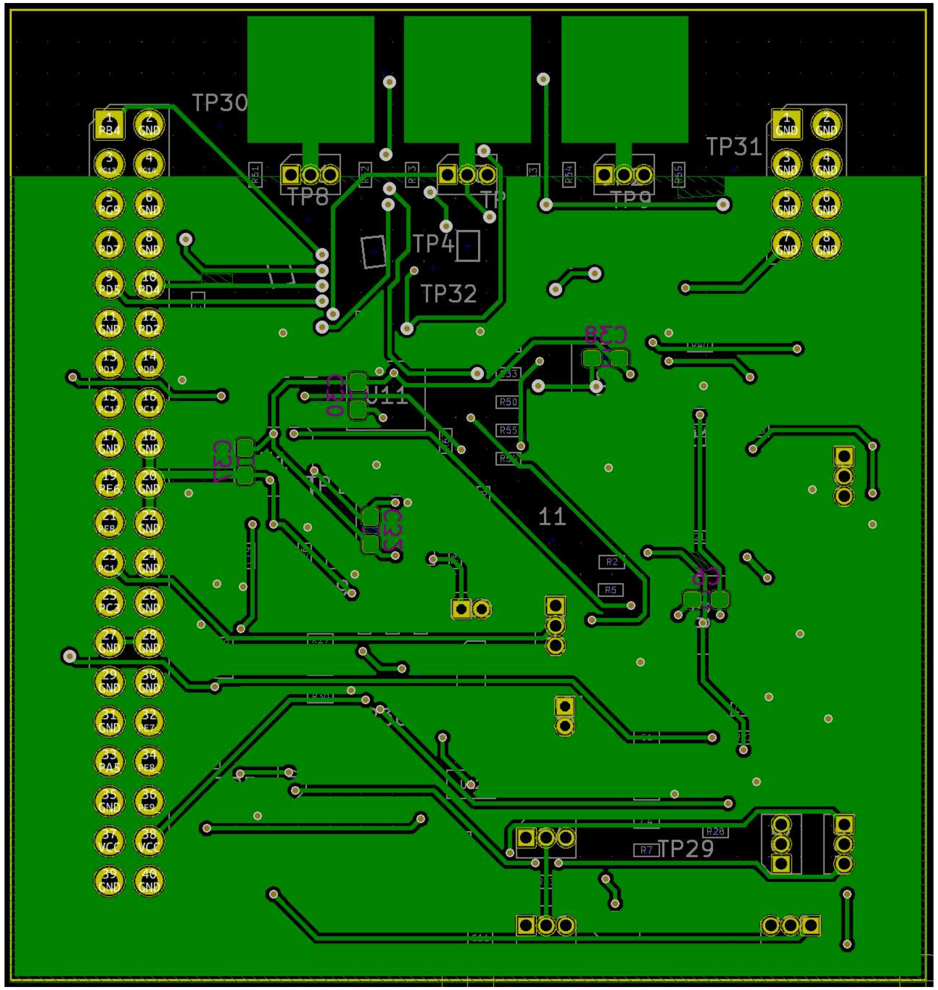
11. Appendix

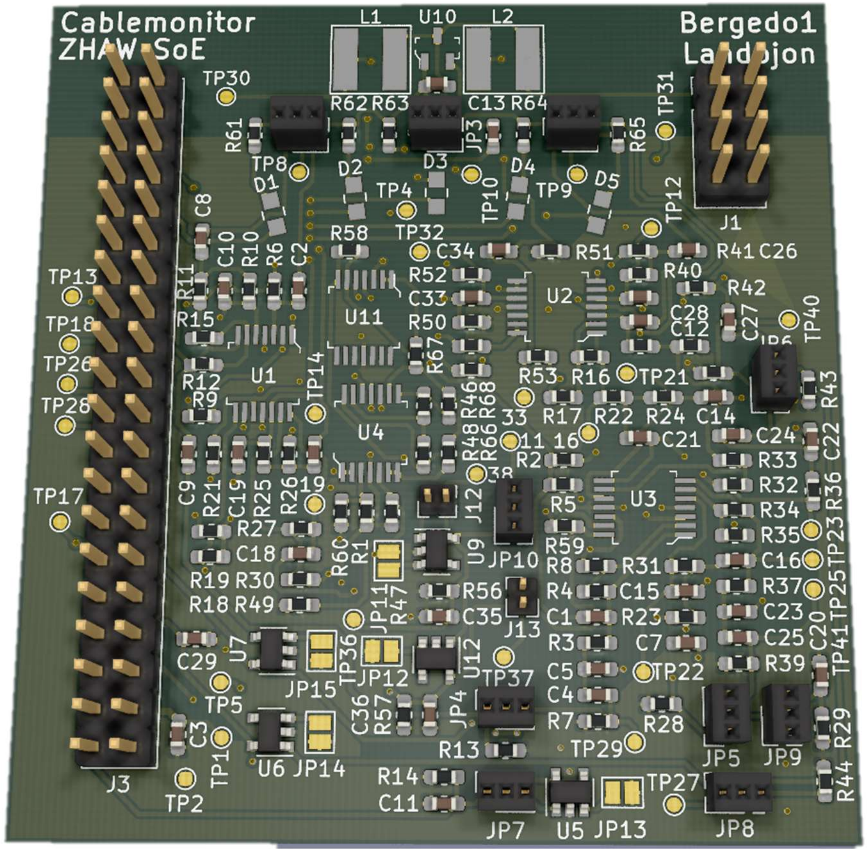
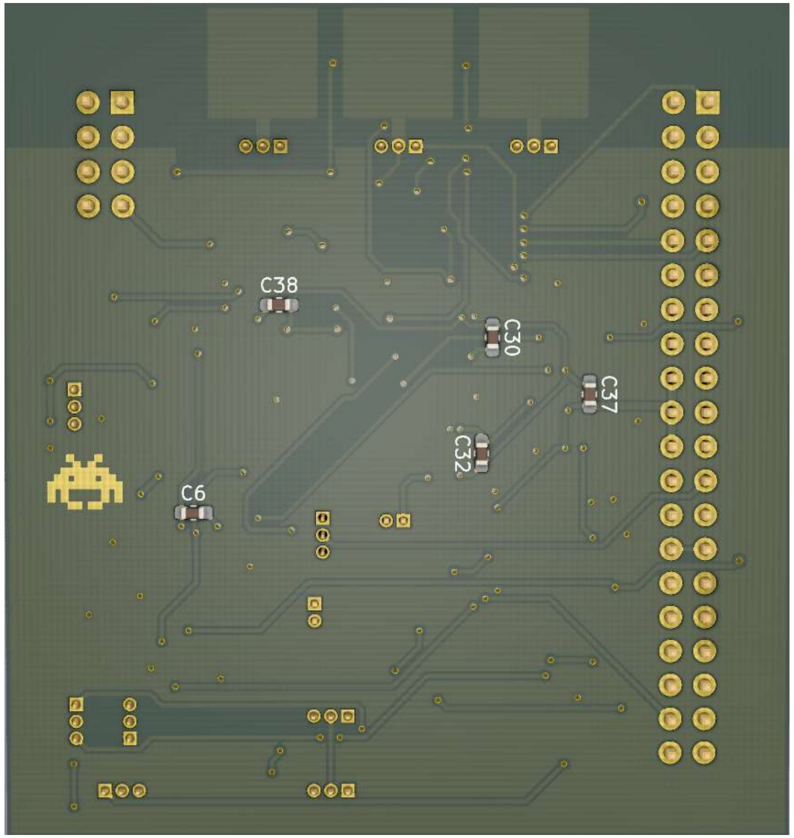
11.1. Schematic



11.2. Layout

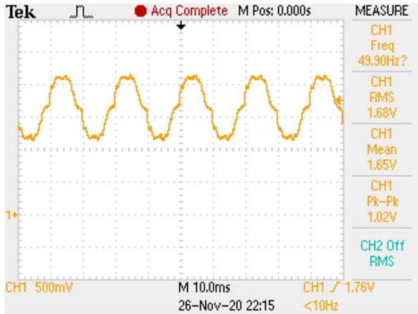
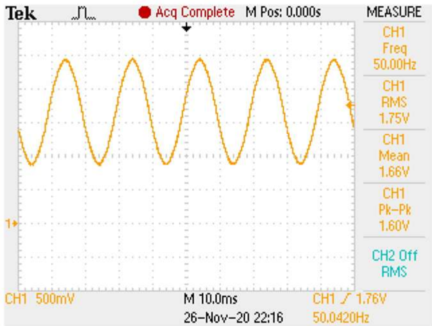


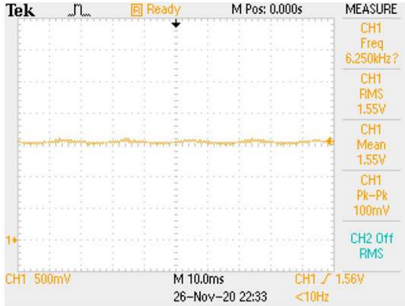
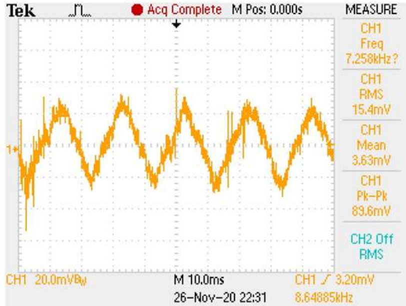
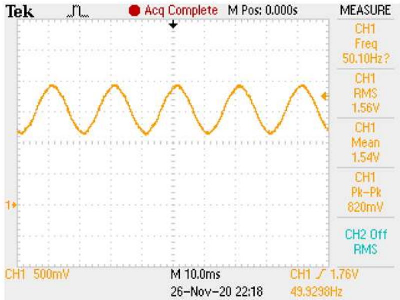
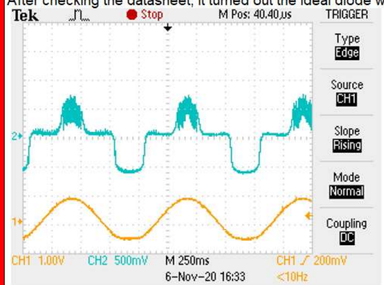


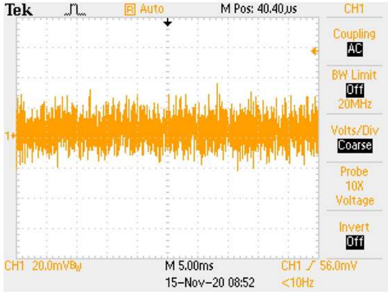
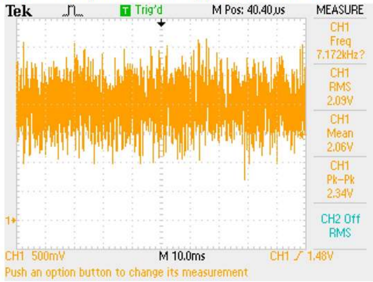
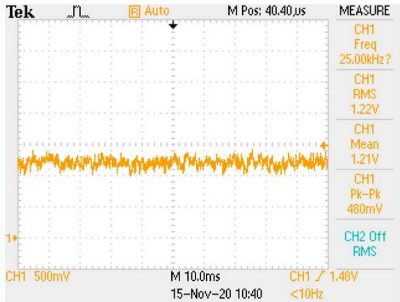

Cablemonitor
ZHAW SoE
Bergedo1


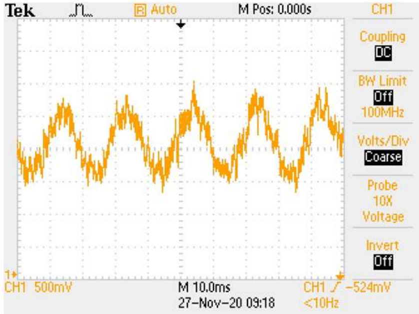
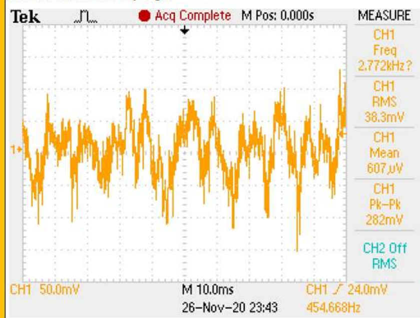
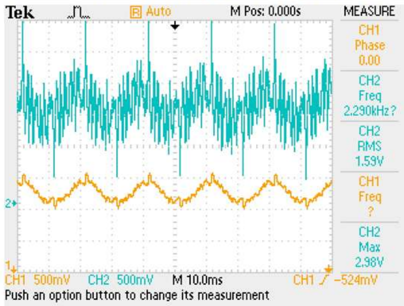
11.3. Test

Unless otherwise specified, all measurements are in respect to GND	DSO	Tektronix TDS2012B; 1GS/s,100MHz, 2 Chanel
VCC = 3V	Fuge	Aim-tti TG5011
	Mulitmeter	Fluke 179

Measurement	Assembling stage	Test conditions	Expected value	Actual value	OK	Discussion
General						
Resistance VCC to GND	unassembled	-	Open loop	Open loop		
Voltage VGND, TP5	Virtual GND	-	1.5V±0.05V	1.54V		
Total Current consumption	"	-	<5mA	2.2mA		
Electrostatic field						
Voltage from EL Pad, TP8		230V cable 5mm distance	~1mVpp sine	Noise<20mVpp		Oscilloscope not sensitive enough
Pad voltage amplified, U1A Pin1	Amplifier (U1A)	230V cable 5mm distance	>1.0Vpp	1.02Vpp		Gain can be changed to get higher amplitudes 
Pad voltage amplified and filtered, TP29	Butterworth complete	230V cable 5mm distance	>1.3Vpp	1.6Vpp		

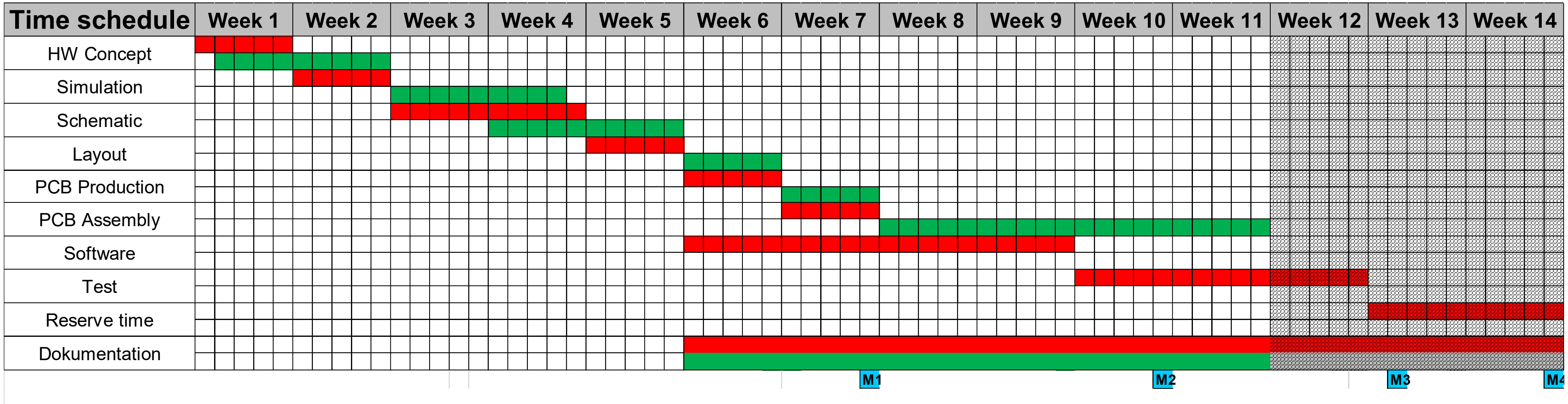
Measurement	Assembling stage	Test conditions	Expected value	Actual value	OK	Discussion
Pad voltage filtered to VGND ,TP13	RC lowpass up to TP13	"	1mV sine, 1.5V offset, 50Hz	1.5V, Noise 20mV		Oscilloscope not sensitive enough
Pad voltage amplified and filtered, TP18	RC lowpass complete	-	Noise < 20mVpp	~60mVpp		Ripple higher than expected. Must be considered in software  
Pad voltage amplified and filtered, TP18		230V cable 5mm distance	>1.0 Vp	0.82Vpp		To get bigger amplitudes, gain can be adjusted 
Pad voltage rectified, TP28	Diode soldered and enabled	"	>1V DC	Current exceeds 20mA, no rectified signal		After checking the datasheet, it turned out the ideal diode works only with voltages higher than 1.5V.  Yellow = Input, Blue = Output As the rectifier is only optional, it can be left out.

Measurement	Assembling stage	Test conditions	Expected value	Actual value	OK	Discussion
Electromagnetic field						
Output hall-sensor, TP4	Hall-sensor	-	1V DC	1V DC with 20mVpp noise		Assemble amplifier and determine if noise is a problem. 
Impedance converter hall-sensor, U11A Pin 1	U11A		1V DC	1V DC with 20mVpp noise		
Reference 2V, U4B Pin 7	U4, R47,R49		2V±0.1V	1.03V		R49 and R47 switched in Schematic
Reference 2V, U4B Pin 7			2V±0.1V	2.02V		
Amplified hall-sensor signal; TP11	hall-sensor complete	-	1.5V with 0.2Vpp	2V with 1Vpp Noise		The noise is amplified to about 1Vpp, not usable for ADC.  --> Add C between Hall-sensor output (TP4) and GND
Amplified hall-sensor signal; TP11		-	1.5V with 0.2Vpp	1.21V with 0.48Vpp noise		Signal is still noisy, but much less than without added C 

Measurement	Assembling stage	Test conditions	Expected value	Actual value	OK	Discussion
Amplified hall-sensor signal; TP11			>0.2Vpp	1Vpp		PCB must be rotated by 90° 
Signal from Coil, TP30	L2, R51	-	1mVpp	Noise<20mV		Oscilloscope not sensitive enough
Signal after amplifying, TP38	Coil completely	-	Noise < 20mVpp, 1.5V offset	~200mVpp		Noise levels are very high.  
Signal after amplifying, TP38	Added filter	Cable 5A, 30mm	>1.0Vpp	500mVpp		Noise levels are very high. Adding a RC(22k, 100nF, fc=72.3Hz) filter after the Output reduces noise drasticaly.  CH1: Filterd with RC; CH2 not filtered

11.4. Timeline

11.4.1. Ongoing



Legend **one rectangle equals to one work day** **projected time** **actual time**

M1 **Milestone 1** **PCB ordered**

M2 **Milestone 2** **HW & SF ready for test**

M3 **Milestone 3** **Testing successful**

M4 **Milestone 4** **End of project, hand in documentation**

11.4.2. **Initial**

ET.PM: Project Management